2005

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Abstract: Natural wetland food plants help meet energetic requirements for sandhill cranes (*Grus canadensis*). Chufa (*Cyperus esculentus*) tubers were found to be a prominent item in the winter diet of cranes in New Mexico and Texas. In 1996 and 1997, chufa production was compared among mowing, discing, and sustained-flooding treatments intended to enhance chufa tuber growth. Sandhill crane numbers were monitored on wetlands during winter flooding to determine treatment preferences. No differences in sandhill crane use of treated wetlands were found in 1996, however in 1997, crane use was higher on disked field than sustained flood fields with mowed fields recording similar use levels as other treatments. Regression analysis also was used to explore the relationship between crane use and above and belowground food production. Chufa mass and fall panicum (*Panicum dichotomiflorum)* seed were positively related to crane use. We hypothesize cranes used wetlands where high biomass of these above and belowground food items was available to efficiently meet daily energetic needs. Disking wetlands at a depth of 5 cm about 30 days following initial wetland drawdown may be an effective treatment to expand chufa production and attract sandhill cranes.

PROCEEDINGS NORTH AMERICAN CRANE WORKSHOP 9:167-171

Key words: chufa, *Cyperus esculentus*, *Grus canadensis*, moist-soil management, New Mexico, sandhill cranes, wetlands.

Behaviorally and physiologically important events for sandhill cranes (*Grus canadensis*) occur on wintering areas. Wintering areas must not only provide for the immediate survival of the species, but for subsequent reproduction (Tacha and Vohs 1987, Krapu and Johnson 1990). Chufa provides 4.26 kcal/g of gross energy (Knaur 1977, Kelley 1986, Fredrickson and Reid 1988) and can potentially meet daily energetic requirements in winter. The tubers are 45 to 77% carbohydrates (mostly starch) and 10 to 14% lipids (Matthiesen and Stoller 1978, Addy and Eteshola 1984, Kelley and Fredrickson 1991). Foods with good lipid composition, such as chufa, can allow cranes to rapidly accumulate 13-18 g/day of fat (Krapu et al. 1985, Krapu and Johnson 1990). Considering that estimated energy requirements for post-breeding greater sandhill cranes (*G. c. tabida*) at 0 °C in New Mexico are about 449.1 kcal/bird/day (Kendeigh et al. 1977, Reinecke and Krapu 1986), chufa represents a potentially important natural food item able to meet these needs.

Chufa tubers are a prominent item in sandhill crane and whooping crane (*Grus americana*) diets on wintering areas. In south Texas, chufa tubers composed over 50% of food volume for sandhill cranes and comprised the bulk of foods eaten (Guthery 1976). In irrigated agricultural valleys of New Mexico, tubers comprised up to 19% of the food volume eaten by sandhill cranes (Walker and Schemnitz 1987). Hunt and Slack (1987) reported that chufa tubers made up 43% of the food volume of a whooping crane shot near Aransas National Wildlife Refuge in Texas.

Although there is information regarding the use of chufa as a food resource by sandhill cranes, information on the response by sandhill cranes to specific wetland management practices to enhance chufa production (Taylor and Smith 2003) is lacking and would be helpful to managers on wintering areas. Therefore, our objectives were to determine sandhill crane preferences for specific chufa production treatments and to explore relationships between crane use and available foods.

STUDY AREA

The study was conducted at the Bosque del Apache National Wildlife Refuge (NWR) (33°48", 106°53") in the Middle Rio Grande Valley of central New Mexico, USA. The Middle Rio Grande basin is bounded by mountain ranges rising 2,000 m to the west and 1,600 m to the east and spans both the Chihuahuan desert scrub and semidesert grassland biotic communities (Brown and Lowe 1980, Brown 1982). Climate is characterized by high light intensity, low relative humidity, high evapotranspiration, and variable rainfall (Johnson 1988). From 1988 to 1997, annual precipitation averaged 24.9 cm with about 50% occurring between 1 July and 30 September (Bosque del Apache NWR NOAA weather station data). During these same years, the average maximum air temperature was 36 °C and the average minimum temperature was -8 °C. Irrigation water is diverted from the Rio Grande north of the refuge and is delivered via irrigation canals and drains for agricultural, wetland, and riparian use.

Fifteen moist-soil wetlands, ranging in size from 0.9 to 5.8 ha served as experimental units for treatment comparisons designed to enhance belowground plant food, primarily chufa, production (Taylor and Smith 2003). Each wetland was served by an interior feeder canal and feeder drain to provide independent field irrigation capability. Wetland soils were domi-

[1] Deceased

nated by clays and clay loams. All fields were laser leveled to a 0.0025% grade and have shallow water impoundment potentials of up to 45 cm depth.

METHODS

Chufa Production Treatments

We randomly assigned mowing, disking, and sustained flooding treatments to wetlands in the study area to assess chufa production enhancement strategies in spring and summer 1996 and 1997. All fields were initially flooded in early April each year and subsequently received 12 irrigations representing an average flood interval of 10-12 days through the end of August (Taylor and Smith 2003). In the mowed treatment, cocklebur (*Xanthium strumarium*) mowing occurred about 2 months after initial drawdown when cocklebur plants were about 15 cm in height to reduce potential competition with chufa through shading (Wills 1975, Jordan-Meloro and Stoller 1978, Keeley and Thullen 1978, Patterson 1982). The disking treatment consisted of disking to a depth of 5 cm 30 days after initial wetland drawdown in an attempt to maximize chufa tuber production through vegetative reproduction (Thumbleson and Kommedahl 1962, Taylorson 1967, Sanchez Tames and Vieitez 1970, Thullen and Keeley 1975, Kelley 1986). The sustained flood treatment required prolonged (70 hours) periods of flooding to drown herbaceous vegetation competing with chufa plants (Merrell 1975).

Winter Flooding

Flooding occurred on the 15 fields during the 1996-1997 and 1997-1998 winter seasons. In order to provide feeding habitat for migratory birds over the entire winter period, we did not flood all fields at the same time. Instead, floodup occurred on 3 randomly chosen fields representing each treatment type on 5 occasions each winter. This variation due to floodup period was removed using a randomized block design. The 5 floodup time periods occurred 23 December 1996, 6 and 20 January 1997, and 3 and 17 February 1997 during the 1996-1997 winter, and 22 December 1997, 5 and 19 January 1998, and 2 and 16 February 1998 during the 1997-1998 winter. During both winters, we inundated wetlands within 24 hours to a depth of 15-20 cm for the 2 week period specified, and then immediately drained them.

Sampling Methods

Above and belowground production (g/m^2) of specific food items was determined for each field. Aboveground seeds, including chufa, bearded sprangletop (*Leptochloa facicularus*), barnyard grass (*Echinochloa crusgalli*), yellow bristlegrass (*Setaria glauca*), *Eriochloa* spp., Johnson grass (*Sorghum halepense*), and fall panicum, were clipped, dried and weighed. Chufa tubers, Johnson grass rhizome, and field bindweed (*Convolvulus arvensis*) rhizome biomass were obtained from soil samples after being washed, separated, dried, and weighed (Taylor and Smith 2003).

During floodup periods each winter, sandhill cranes were counted 3 days per week on each of 3 treatment fields from 0730-1630 hourly using a 60x spotting scope. Counts were made from vantage points removed from the immediate study area to avoid disturbance. Each field was therefore counted on 60 occasions during the 2-week flood period. These counts were averaged and multiplied by the number of flood days to generate total crane use-days on each field for the entire flood period. To adjust for varying field sizes, total crane use days were divided by the number of field hectares to generate crane density per hectare for each field.

Data Analysis

Differences in sandhill crane use days among treatments were determined using a randomized block design. A repeated-measures ANOVA with treatment as the main plot factor and year as the repeated-measures factor weas used in these analyses. Treatment comparisons required Tukey's test for nonadditivity (Tukey 1949) which was used to test for block by treatment interaction. Sphericity was assessed using Kirk's Three-step Testing Strategy (Kirk 1982). Fisher's Least Significant Difference was used as a mean separation test (Milliken and Johnson 1992). Significance was determined at the $\alpha < 0.10$ level for all tests.

Multiple regression was used to explore the relationship between average crane use days per hectare as the dependent variable and seed, tuber, and rhizome mass (g/m^2) as explanatory variables on each field. Aboveground food resource explanatory variables included chufa, bearded sprangletop, barnyard grass, yellow bristlegrass, *Eriochloa* spp., Johnson grass, and fall panicum seeds. Belowground food resource explanatory variables included chufa tuber mass, and Johnson grass and field bindweed rhizome mass. 1996 and 1997 data were combined in this analysis and significance was determined at the $\alpha < 0.10$ level.

RESULTS

Sphericity was satisfied for sandhill crane use days in the treatment comparison. A treatment by year interaction occurred for sandhill crane use days ($F_{2,8} = 2.73$, $P = 0.10$). Log transformation was required to satisfy normality for within-year analyses rendering median values following back-transformation. There was no block by treatment interaction for within year analysis in 1996 ($F_{2,8} = 0.10$, $P = 0.76$) or 1997 ($F_{2,8} = 0.001$, $P = 0.96$). No statistical differences ($F_{2,8} = 2.67$, $P = 0.13$) were recorded for sandhill crane use days of treated wetlands in 1996, however there were differences among treatments in 1997 ($F_{1,8} = 3.08$, $P = 0.10$). In 1997, crane use was higher

Table 1. Median sandhill cranes per hectare on mowed, disced, and sustained flood treatments at the Bosque del Apache National Wildlife Refuge, New Mexico during winter (December, January, and February) 1996-1997 and 1997-1998.

Treatment Year	Median	Confidence Interval (±)
Mowed		
1996	78.2a[1]A[2]	1.4
1997	44.9abB	2.2
Disked		
1996	50.2aA	1.6
1997	72.7aB	1.5
Sustained Flood		
1996	19.3aA	2.1
1997	13.6bB	2.4

[1] Treatment medians followed by the same lower case letter are not different ($P > 0.10$).
[2] Year medians followed by the same upper case letter are not different ($P > 0.10$).

on disced fields than on sustained flood fields but crane use on mowed fields did not differ from either of these treatments (Table 1). Although not statistically significant in 1996, crane use of wetlands was also lowest in the sustained flood treatment.

Chufa tuber mass and fall panicum seed explained 52.4% ($R^2 = 0.52$, $P < 0.001$) of the variation in sandhill crane use days on all fields in 1996 and 1997 (Table 2). Other explanatory variables including Johnson grass (partial $r^2 = 0.1$, $P = 0.88$), bearded sprangletop (partial $r^2 = 0.3$, $P = 0.65$), barnyard grass (partial $r^2 = 4.2$, $P = 0.12$), yellow bristlegrass (partial $r^2 = 2.6$, $P = 0.16$), *Eriochloa* spp. (partial $r^2 = 0.06$, $P = 0.84$), chufa (partial $r^2 = 0.3$, $P = 0.62$) seeds, and Johnson grass (partial $r^2 = 2.7$, $P = 0.20$) and field bindweed rhizomes (partial $r^2 = 3.0$, $P = 0.33$), were not statistically related to sandhill crane use days.

DISCUSSION

Although sandhill crane use did not differ among treatments in 1996, use did in 1997. Use closely mirrored differences found for chufa mass production where production was higher on disked fields than on sustained flood fields (also observed in 1996 by not statistically significant) but not different from mowed fields on either of these treatments (Taylor and Smith 2003). Cranes used fields with the most chufa mass and may have been especially attracted to disked fields in 1997 as chufa mass doubled from production levels recorded in 1996. Disking may therefore be an effective management practice for enhancing chufa production in managed wetlands for cranes. Although not statistically discernable from the mowed treatment, individual chufa tuber mass (g/tuber) was also highest in the disked treatment. The high individual chufa tuber mass recorded on disked fields indicated fewer, but larger tubers were available compared with other treatments (Taylor and Smith 2003). Tactile cues employed by cranes while probing subsurface areas are the most probable means of locating potential foods such as chufa tubers. Larger tubers in the disked treat-

Table 2. Significant ($P > 0.10$) regression model variables explaining sandhill crane use on 30 moist-soil managed wetlands in 1996 and 1997 on the Bosque del Apache National Wildlife Refuge, New Mexico.

Dependent Variable	*n*	Independent Variable	Partial r^2 (x 100)	$P > F$
Sandhill cranes/ha	30	chufa tuber mass (g/m^2)	41.3	0.0001
Sandhill cranes/ha	30	fall panicum seed (g/m^2)	13.3	0.01

ment might therefore provide a more detectable food item for meeting required daily caloric intake for sandhill cranes until foraging efficiency thresholds declined (Fredrickson and Drobney 1979).

The strong relationship found between sandhill crane use and chufa production on treatment fields in this study supports the importance of this food item in the diets of cranes found by earlier researchers (Guthery 1976, Hunt and Slack 1987, Walker and Schemnitz 1987). In this study, chufa was the most important food item affecting crane use.

It is unlikely that sandhill cranes would effectively forage on the small seeds produced by fall panicum, however the relationship between cranes and this annual graminoid may indicate use of plant parts other than its seed. Corms, the enlarged fleshy base of graminoid stems, have been cited as important summer food items for sandhill cranes in Idaho (Mullins and Bizeau 1978). Hitchcock (1971) reported at least one species of this *Panicum* genus as possessing a thick corm base. Lack of statisitical significance for barnyard grass and yellow bristlegrass may also be misleading due to small sample sizes. Probability values for these species were nearly significant and corms for these species may also be important dietary items. Questions, regarding the utilization of energetically important corms by sandhill cranes on wintering areas requires further research.

The Rocky Mountain population (RMP) of greater sandhill cranes occupies arid irrigated valleys and basins across their winter range in the southwestern United States and the Mexican Interior Highlands (Drewien and Bizeau 1974). Recent wetland habitat loss due to groundwater mining and prolonged drought within portions of this range (J. Taylor, personal observation) is of concern to managers and biologists with management responsibilities for the population. In this study, over 48,000 sandhill crane use days were recorded on just 56 ha of managed wetland habitat. These wetland fields were converted from flood irrigated agriculture at nominal cost and managed to provide natural moist-soil vegetation for migratory birds (Fredrickson and Taylor 1982). Historically, water use for moist-soil vegetation production was comparable to agricultural crops (Taylor 2000) but overall water use has been reduced annually since 1998 without compromising wetland vegetation production (Bosque del Apache National Wildlife Refuge, unpublished data). More intensive moist-soil management on small converted agricultural fields across the arid Southwest could therefore provide important wetland food resources for the RMP sandhill population in the face of ongoing habitat loss and drought.

ACKNOWLEDGMENTS

We thank L. Brown, R. DelloRusso, M. Gallager, B. Hayes, D. Hawksworth, J. Kneuner, C. Lee, M. Oldham, and S. Scolari for their field assistance. L. M. Smith was supported by the Caesar Kleberg Foundation for Wildlife Conservation. This is manuscript T-9-1003 of the College of Agricultural Sciences and Natural Resources, Texas Tech University. We thank D. Johnson and R. Drewien for helpful comments on the manuscript.

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